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COMPLETE SPECIFICATION.

Improvements in or relating to Acceleration Control Systems.

We, THE EXPRESS LIFT COMPANY LIMITED, of Greycoat Street, London, S.W.1, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to acceleration control systems and is applicable, for example, to the control of acceleration of an electric motor which is arranged to move a load from a first position to a second position. The word "acceleration" is used here to denote both acceleration and retardation and is to be construed accordingly except where the context clearly requires otherwise.

The invention is concerned more particularly, but not exclusively, with control systems for electrically operated lifts, hoists and the like, herein referred to as lifts.

The efficiency of a lift depends upon its ability to transfer its load from one floor to another in the least time consistent with mechanical limitations inherent in the lift system and, in the case of a passenger lift, with the comfort of the passengers. The first factor is governed principally by the maximum permissible traction force between the driving sheave and the lift cable, while the second factor is governed principally not by the absolute value of the acceleration of the lift but by the rate of change of such acceleration. In an ideal lift system, therefore, the speed of the lift would be varied between zero and a maximum value at a maximum rate, that is to say, the acceleration would be maintained at a maximum value, determined by the mechanical limitations of the system, for the greatest possible part of the acclera-tion time, and the acceleration between zero and this maximum value would be varied at a constant rate.

One object of the present invention is to provide an improved control system for an electrically operated lift, which takes these considerations into account.

It is to be understood however that the invention in its broadest aspects is not limited to lift systems, but is applicable, for example, to control arrangements for machine tools.

According to one aspect of the present invention, an acceleration control system includes means for comparing a first signal which is a function of the acceleration of a controlled member with a second signal which is a function of the speed of said member and controlling the acceleration in dependence upon the comparison so as to maintain a predetermined relationship between the two signals and thereby to maintain the acceleration as a predetermined function of the speed such that any change in the acceleration is effected at a predetermined constant rate.

The system may include means for modifying the relationship between the second signal and the speed of the member in dependence upon a predetermined speed being reached, and may also include control means which are arranged to become operative, as the member approaches a predetermined position, to control the movement of the member in dependence upon a comparison made between a signal which is a function of the speed of the member and a further signal which is a function of the distance of the member from said predetermined position, so as to vary the speed in a predetermined manner.

According to another aspect of the present invention, an acceleration control system for

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controlling an electric motor which is arranged to move a load from a first position to a second position, comprises acceleration responsive means for producing a first signal dependent upon the acceleration of the load, speed-responsive means for producing a second signal dependent upon the speed of the load, means for modifying the said second signal to produce a pattern acceleration signal which is a predetermined function of the speed, and means for influencing the torque of the motor so as to maintain a fixed relation between said first signal and the pattern acceleration signal, the arrangement being such that any change in the acceleration of the motor is effected at a predetermined constant rate.

As applied to an electric motor driven lift, said means for modifying the second signal may be adapted to produce a pattern acceleration signal which, during acceleration of the lift to a predetermined maximum speed, increases initially as the square root of the speed from zero to a value not exceeding a predetermined maximum value, and subsequently as the maximum speed is approached, decreases as the square root of the difference between the maximum speed and the actual speed from the said maximum value to zero. Means may be provided for modifying the pattern acceleration signal, during retardation of the lift, to ensure that the lift reaches a decking position with zero acceleration and at zero, or creep speed.

In order that the invention may be clearly understood, one acceleration control system in accordance with the present invention, as applied to control of an electric motor driven lift, will now be described by way of example with reference to the drawings accompanying the Provisional Specification, in which:—

Figure 1 is a schematic circuit diagram of the control system;

Figures 2—5 and 7 are explanatory diagrams which will be referred to to explain the operation of the control system; and

Figures 6, 8 and 9 are detailed circuit diagrams showing modifications of the circuit shown in Figure 1.

Referring to the drawings, and particularly to Figure 1, an electric lift system having a winding motor 1 with a field winding 2, comprises essentially a Ward-Leonard generator 3 arranged to supply the motor through a resistance 4, and a magnetic amplifier 5 feeding the field winding 6 of the generator in accordance with electrical control signals fed to the amplifier, these control signals being controlled automatically in accordance with a required motor torque as described hereinafter.

Coupled with the shaft 7 of the motor are a tachometer generator 8 for providing an electrical signal V proportional to the speed of the motor, an accelerometer 9 for producing an electrical signal proportional to the acceleration of the motor, and two potentiometers 10 and 11 which are adapted to provide electrical signals x and e_v respectively each of which is a function of the actual position of the lift.

The output of the magnetic amplifier 5 is controlled in accordance with three input signals, a first signal fed from one end of the resistance 4 which is proportional to the armature current of the motor, a second signal V from the tachometer generator 8, and a third signal which is dependent upon the position of a relay operated changeover switch 12. The first and second control signals are feedback signals for compensating for IR losses in known manner, and for increasing the speed of response of the Ward Leonard system respectively. In the position shown of the changeover switch 12, the third signal is obtained from a subtracting circuit 13 and its magnitude is equal to the difference between a signal "a" from the accelerometer 9 and a signal obtained from a control circuit comprising a changeover switch 14, a selector circuit 15, a "square-rooting" circuit 16, a voltage reversing circuit 17 and a further selector circuit 18. The selector circuit 15 is adapted to select the smallest of three signals applied to it, these being a signal V from the tachometer generator 8 or a signal V_b, depending upon the position of a changeover switch 19, a signal V_m—V from a further subtracting circuit 20 to which are applied a signal V from the tachometer generator 8 and a constant signal V_m, and a signal V_a or V_b depending upon the position of a changeover switch 21.

The selector circuit 18 is adapted to select the smaller of two signals, one being the output signal from the voltage reversing circuit 17, and the other being obtained from a further control circuit comprising a dividing circuit 22, a squaring circuit 23, a subtracting circuit 24 and a circuit 25 for producing a signal x_a in accordance with a signal "a" fed thereto from the accelerometer 9. The output from the selector circuit 18 is, of course, only fed to the subtracting circuit 13 when the changeover switch 14 is in its alternative position not shown.

In the alternative position of the changeover switch 12, the third signal fed to the amplifier 5 is obtained from a subtracting circuit 26 which is adapted to produce an output equal in magnitude to the difference between a signal e_v fed thereto from the potentiometer 11 and a signal V from the tachometer generator 8. A further signal from the subtracting circuit 26 is fed to a relay 27 whose operation is described hereinafter.

In describing the operation of the control arrangement, reference will be made to

Figures 2, 3, 4 and 5 of the drawings; the operation will be described in two parts, the first part dealing with its operation during acceleration of the motor to a maximum speed, and the second part dealing with its operation during retardation of the motor from the maximum speed to zero.

It will be appreciated that the maximum speed attained by the motor will be selected in accordance with the distance the lift has to travel between two floors, and, as has already been mentioned, the maximum permitted acceleration of the motor is limited by mechanical considerations while consideration of passenger comfort sets a limit on the rate of change of acceleration.

Referring to Figures 2 and 3, which show respectively a speed-time diagram and an acceleration-time diagram of the lift, the system is designed to control the change of acceleration at a predetermined uniform rate between zero and a maximum value, the acceleration being increased linearly from zero to a value not exceeding the maximum value, which will be determined by the required maximum speed of the lift. In Figure 3, the rate of change of acceleration is given by the slope of the lines AB and CD, there being shown four graphs a_1, a_2, a_3 and a_4 corresponding to maximum speeds V_{m1}, V_{m2}, V_{m3} and V_{m4}, and the four corresponding speed-time graphs are shown in Figure 2.

The manner of control of the arrangement during acceleration of the motor is based upon the fact that for uniform rate of change of acceleration, the speed is linearly dependent upon the square of the acceleration; thus it can be shown that

$$a^2 = 2rV^1$$

where a is the acceleration;
r is the predetermined value of rate of change of acceleration; and
V^1 is a quantity linearly dependent upon the speed.

It will be seen therefore that if V_m is the maximum speed for a given wind, then the acceleration at any point on the part AB of the graph in Figure 3 can be represented by the equation

$$a = \sqrt{2rV};$$

the acceleration at any point on the part CD of the graph can be represented by the equation

$$a = \sqrt{2r(V_m - V)};$$

and at any point on the part BC of the graph the acceleration has a constant value $\sqrt{2rV_a}$, where V_a is the speed at point B. Thus in order to obtain an acceleration pattern as shown in Figure 3 it is necessary to obtain control signals having values $\sqrt{2rV}$, $\sqrt{2rV_a}$, and $\sqrt{2r(V_m - V)}$ respectively, which are fed to the amplifier 5 in succession.

In operation of the control system, for acceleration of the motor 1, the initial speed and acceleration of the motor are zero and the lift is in its initial position; the changeover switches 12, 14 and 19 are in the position shown in Figure 1. A small initial disturbance of the motor causes a small signal V to be generated by the tachometer generator 8 and this signal V is fed via the changeover switch 19 to the selector circuit 15. Simultaneously with the signal V, a signal $V_m - V$ from the subtracting circuit 20 and a signal V_a via the changeover switch 21, are fed to the selector circuit 15; initially, of course, the signal V is much less than either of the other signals and is therefore selected and passed to the circuit 16. In Figure 1 the output signal from the circuit 15, equal to V, is denoted by V^1. The output signal from the circuit 16 has a value equal to $\sqrt{2rV^1}$ and this is fed via the selector switch 14 to the subtracting circuit 13, the output of which has a value $\sqrt{2rV^1} - a$ where a is the signal from the accelerometer 9. Now the amplifier 5 is adapted to influence the motor torque through the Ward-Leonard drive in such a manner as to reduce this error signal $\sqrt{2rV^1} - a$; it will be seen therefore that the acceleration under these conditions will be equal to the value $\sqrt{2rV^1}$ which acts as a pattern acceleration signal, and the acceleration will increase at a uniform rate.

When the speed of the motor is such that the signal V is larger than the constant signal V_a, the latter will be selected by the selector circuit and consequently the pattern acceleration signal, and therefore the acceleration of the motor will be held at a constant value $\sqrt{2rV_a}$. The point at which the signal V_a becomes selected is represented by the point B in Figure 3, V_a being equal to the speed of the motor when the maximum permissible acceleration is reached. At a point corresponding to the point C in Figure 3, the signal $V_m - V$ from the subtracting circuit 20 becomes smaller than the signal V_a, and is therefore selected in place of the latter. The pattern acceleration signal therefore has a value $\sqrt{2r(V_m - V)}$ and this decreases linearly to zero, that condition being reached when the speed of the motor is a maximum and the lift will move at a maximum speed until further control means become operative to decelerate the motor.

Deceleration of the motor is initiated when the lift reaches a predetermined position at which an inductor is operated to change the changeover switch 14 to its alternative position. This has the effect, because of the

presence of the voltage reversing circuit 17, of producing a pattern retardation signal having successive values, $2r\sqrt{(V_m-V)}$, $\sqrt{2rV_a}$ and $\sqrt{2rV}$, and the motor is retarded smoothly, rates of change of the retardation being uniform.

Before the final stages of the retardation are described, however, reference will be made to Figures 4 and 5. Figure 4 shows graphically how the speed of the motor V decreases from a value V_m to zero as the lift approaches the final decking position, the ordinates of the graph being the square of the velocity and the distance x of the lift from its final decking position. It will be appreciated that using these co-ordinates the slope of the curve is proportional to the retardation. At the point A, retardation is initiated and the velocity decreases from a value V_m to a value $(V_m - V_a)$ at point B where maximum retardation is reached. The retardation remains constant at its maximum value until point C on the curve is reached and thereafter the retardation decreases to zero at a uniform rate, the speed and retardation of the lift becoming zero as the lift reaches its final decking position.

However, the curve ABCO in Figure 4 represents an ideal condition in which no errors have arisen in the system; clearly if any errors do arise it may be impossible to bring the retardation and the speed to zero simultaneously when the lift is in the required position. In the figure, the line BC is of constant slope, this being proportional to the maximum value of the acceleration reached.

Referring to Figure 5 now, which illustrates graphically how the speed and retardation can be made to vary in such a way as to become zero at the required position, the curve ABF shows how the speed would vary if the retardation were controlled in accordance with the pattern retardation signal of value $2\sqrt{r}\ (V_m - V)$ and the curve ECO shows how the speed should be made to tend towards zero at the origin O, this curve being represented by the equation

$$V^2 = kx^{4/3}.$$

In order to vary the speed of the lift so that initially its speed and position are represented by point A on the first curve and finally by the point O on the second curve, without varying the retardation in a non-uniform manner, it is necessary to introduce a transition retardation control whereby the movement of the lift is represented by the line BC, this line being tangential to the two curves. The slope of the line BC can be shown to be $V_1^2/2(x_1 - x_a)$ where V_1 and x_1 are the speed and position at any point on the line BC which is tangential to the curve ECO.

Considering the value of the retardation given by the above expression and the value given by the expression $\sqrt{2r(V_m - V)}$ it will be seen then on the part AB of the curve the former is always greater than the latter; this fact is utilised in controlling the final part of the movement. The method of operation of the arrangement shown in Figure 1 for controlling motion of the lift in the manner described by the curve ABC in Figure 5 will now be described with particular reference to these two figures.

At the position at which retardation is to be initiated, that is to say at point A on the curve, the changeover switch 14 is caused to move to its alternative position, say by operation of an inductor. At the same time, changeover switches 19 and 21 move to their alternative positions; the signal V_b has a constant value greater than V_m, and thus it is ensured that the selector circuit 15 does not select any signal having a smaller value than $V_m - V$ during retardation. A pattern retardation signal having the value $\sqrt{2r(V_m - V)}$ is fed from the selector circuit 18 to the subtracting circuit 13, V_m being the value of the signal V before the lift starts to decelerate. The pattern retardation signal increases at a uniform rate until, at point B on the curve, it is no longer smaller than the signal fed to the selector circuit 18 from the dividing circuit 22 and having the value $V_1^2/_2(x_1 - x_a)$. From point B, the latter signal becomes the new pattern retardation signal and the motion of the lift becomes that described by part BC of the curve. During this part of the motion a pattern speed signal e_v from the displacement potentiometer 11 is compared with a signal V from the tachometer generator 8 by means of the subtracting circuit 26; the signal e_v is a function of the position of the lift which is such as to correspond to the curve ECO in Figure 5; the line BC has been chosen so as to be tangential to both curves ECO and ABD.

When the lift reaches the position corresponding to point C the signal e_v becomes equal to the signal V and the difference signal $e_v - V$ becomes zero. Consequently the relay 27 is energised, and remains energised, and operates the changeover switch 12. At this point therefore the pattern retardation signal $V_1^2/_2(x_1 - x_a)$ ceases to be effective and the motor is now controlled in accordance with the pattern speed signal e_r, the difference or error signal $e_v - V$ being fed to the amplifier 5. Thus the motion of the lift continues until the lift reaches the desired decking position corresponding to the origin of the curve in Figure 5, the lift reaching this position at zero speed and zero acceleration. It will be seen moreover that during the retardation, the retardation is either constant, part BC of the curve, or changes at a constant rate, parts AB and CO of the curve.

In the arrangement so far described, means are provided for producing a pattern re-

tardation signal of magnitude $V_1^2/_2(x_1 - x_a)$ for controlling the motion of the lift along the part BC of the curve in Figure 5. The arrangement may however be considerably simplified by modifying such means so as to produce a signal of the form $a^1 = (V_1^2 + k_a)/2x_1$ where k_a is a value depending upon the signal a^1.

Thus, referring to Figure 7, the slope of the line AB is $-(V_1^2 + k_a)/(2x_1)$, the required signal, and this is a particularly convenient quantity to compute since the quantity x_1 can be represented by the displacement of a potentiometer. One circuit for producing such a signal is illustrated in Figure 8.

Referring to Figure 8, a signal V_1^2 is fed through a resistance R_1 to a high gain amplifier 33 across the output of which is a potentiometer P. The tapping of the potentiometer P, connected through the resistance R_2 to the input of the amplifier, is adapted to feed back a signal p, the signal p and the position of the tapping being a function of the distance x_1 of the lift from its decking position. The signal p has in fact the value $2ax_1$. A further signal k_a is arranged to be fed back to the amplifier through a resistance R_3, this signal being derived from a device 32 for producing the signal k_a in dependence upon the value of an input signal a thereto.

Since the amplifier is of high gain, the voltage e at the input to the amplifier will be very much smaller than any of the signals V^2, k_a, or p. If then the resistances R_1, R_2 and R_3 are of equal value it will be seen that

$$\tfrac{1}{3}(V^2 + p + k_a) = e = 0$$

$$\text{or } V^2 + k_a = -p$$

$$\text{Now since } p = 2\,ax_1$$
$$a = -(V^2 + k_a)/2x_1$$

which is the required output signal. The device 32 is adapted to produce the required output signal only when the input signal thereto is a. It may comprise non-linear resistances or may be adapted to produce a suitable linear approximation of the form

$$ka = \text{constant} + (\text{constant} \times a).$$

An alternative method of controlling the motion of the lift to its final decking position involves the use of a pattern retardation signal during the whole of the retardation period.

If the retardation be given by the expression

$$a = -\tfrac{2}{3}.\ V^2/_2x$$

where a is the retardation;
V is the speed; and
x is the distance of the lift from its final position,

it will be seen that the values of a, V and x all become zero simultaneously and the retardation changes at a uniform rate.

Thus, referring to Figure 5, the motion of the lift may be controlled in the required manner by means of a pattern retardation signal of magnitude $\sqrt{2r(V_m - V)}$ over the part AB of the curve; a pattern retardation signal of magnitude $(V^2 + k_a)/2x$ over the part BC of the curve; and a pattern retardation signal of magnitude $\tfrac{2}{3}V^2/x$ over the part CO of the curve, each of the signals becoming smallest in magnitude, and therefore selected, in turn as the final position is approached.

A circuit arrangement for producing the second and third of these signals is shown in Figure 9 and referring to this figure, the pattern retardation signal is derived from a dividing circuit 35 to which are fed a signal x in dependence upon the position of the lift and a signal from a selector circuit 36 which is adapted to select the smaller of two signals of magnitude $\tfrac{2}{3}V^2$ and $\tfrac{1}{2}(V^2 + k_a)$ respectively. A device 39 is adapted when fed with a signal of magnitude V^2 to produce the signal of magnitude $\tfrac{2}{3}V^2$, while a further device 37 is adapted, when fed with a signal V^2 and a signal k_a from a circuit 38 the latter being fed with a signal a, to produce the signal of magnitude $\tfrac{1}{2}(V^2 + k_a)$.

Clearly, in order to apply this circuit arrangement to the general arrangement shown in Figure 1, the parts referenced 11, 12, 26 and 27 would be omitted from the latter and the circuit shown in Figure 9 would replace the parts referenced 22, 23, 24 and 25, the dividing circuit 22 being replaced by the dividing circuit 35.

In order that the speed of the lift may be controlled down to a creep speed, instead of to rest, the arrangement illustrated in Figure 1 may be modified in the manner shown in Figure 6, the latter figure showing a detail of the modified arrangement. Referring to Figure 6, the selector circuit 15 is arranged to select the smallest of three signals of magnitudes V_a, $V_m - V$, and $V - V_c$ respectively, where the symbols V_a, V_m and V have the meanings previously assigned to them and where V_c is a signal whose magnitude is proportional to the desired creep speed. The modification comprises the provision of a further subtracting circuit 30 via which the signal V is fed to the selector circuit 15, and changeover switch 31 which in one position selects the signal V_c to be fed to the subtracting circuit and which in the other position selects a zero signal so that the arrangement operates as if no such modification has been made. It will of course be appreciated that with this modification it will be quite unnecessary to provide a changeover switch such as 12, Figure 1, for selecting a pattern speed signal towards the end of the wind.

Although the invention has been describe

with particular reference to a lift system, having a driving motor whose torque is controlled by means of electrical control signals, it is to be understood that in its broadest aspect the invention is applicable to the control of any prime mover, by means of control signals which are not necessarily electrical. Thus the control signals may be provided, for example, by any suitable mechanical or hydraulic means.

WHAT WE CLAIM IS :—

1. An acceleration control system including means for comparing a first signal which is a function of the acceleration of a controlled member with a second signal which is a function of the speed of said member and controlling the acceleration in dependence upon the comparison so as to maintain a predetermined relationship between the two signals and thereby to maintain the acceleration as a predetermined function of the speed such that any change in the acceleration is effected at a predetermined constant rate.

2. An acceleration control system as claimed in Claim 1, wherein means are provided for modifying the relationship between the second signal and the speed of the member in dependence upon a predetermined speed being reached.

3. An acceleration control system as claimed in Claim 1 or Claim 2, wherein control means are arranged to become operative, as the member approaches a predetermined position, to control the movement of the member in dependence upon a comparison made between a signal which is a function of the speed of the member and a further signal which is a function of the distance of the member from said predetermined position, so as to vary the speed in a predetermined manner.

4. An acceleration control system for controlling an electric motor which is arranged to move a load from a first position to a second position, comprising acceleration-responsive means for producing a first signal dependent upon the acceleration of the load, speed-responsive means for producing a second signal dependent upon the speed of the load, means for modifying the said second signal to produce a pattern acceleration signal which is a predetermined function of the speed, and means for influencing the torque of the motor so as to maintain a predetermined relationship between the said first signal and the pattern acceleration signal, the arrangement being such that any change in the acceleration of the motor is effected at a predetermined constant rate.

5. An acceleration control system as claimed in Claim 4, and for controlling an electric motor driven lift, wherein said means for modifying the second signal are adapted to produce a pattern acceleration signal which, during acceleration of the lift to a predetermined maximum speed, increases initially as the square root of the speed from zero to a value not exceeding a predetermined maximum value, and subsequently as the said maximum speed is approached, decreases as the square root of the difference between the maximum speed and the actual speed from said maximum value to zero.

6. An acceleration control system as claimed in Claim 5, wherein means are provided for modifying the pattern acceleration signal, during retardation of the lift, to ensure that the lift reaches a decking position with zero acceleration and at zero, or creep, speed.

7. An acceleration control system as claimed in Claim 6, wherein said means for influencing the torque of the motor are operative in dependence upon a selected one of two error signals, the first error signal representing any discrepancy between the actual acceleration and a pattern acceleration, and the second error signal representing any discrepancy between the actual speed and a pattern speed, there being provided switching means normally operative to select the first of said error signals but operative during retardation of the lift, upon the discrepancy between the actual speed and the pattern speed becoming zero, to select the second of said error signals, means arranged to become operative during retardation of the lift when the pattern acceleration attains a value equal to that at which said switching means become operative to select the second error signal to maintain the pattern acceleration at that value until said switching means become operative to select the second error signal, and means for controlling the pattern speed in accordance with the position of the lift in such a manner as to ensure that the lift reaches the decking position with zero acceleration and at zero, or creep, speed.

8. An acceleration control system as claimed in any one of Claims 4 to 7, wherein the motor is a direct current electric motor having a Ward-Leonard drive, and the torque influencing means comprise a magnetic amplifier arranged to control the field excitation of the Ward-Leonard generator in accordance with a control signal fed thereto.

9. An acceleration control system as claimed in any one of Claims 4 to 8, wherein the acceleration-responsive means and the speed-responsive means respectively comprise an accelerometer and a tachometer generator mounted on a shaft driven by the motor.

10. An acceleration control system as claimed in any one of Claims 5 to 7, wherein said means for modifying the said second signal comprise a selector circuit adapted to select the smallest of three electrical signals fed thereto; means for feeding said selector circuit with electrical signals respectively

proportional to the actual speed of the lift, the difference between said maximum speed and the actual speed, and a predetermined speed; a circuit adapted to produce a first pattern acceleration signal proportional to the square root of the magnitude of the selected one of said three signals; means for producing a second pattern acceleration signal of equal magnitude but opposite polarity to said first pattern acceleration signal; and a changeover switch operative to select the first or second of said pattern acceleration signals in dependence upon whether the lift is to be accelerated or retarded.

11. An acceleration control system for controlling an electric motor driven lift, substantially as hereinbefore described with reference to Figures 1 to 5 of the drawings accompanying the Provisional Specification.

12. An acceleration control system for controlling an electric motor driven lift, substantially as hereinbefore described with reference to Figures 1 to 5, and modified as described with reference to Figure 6, or Figures 7, 8 and 9 of the drawings accompanying the Provisional Specification.

For the Applicants:
F. S. PEACHEY,
Chartered Patent Agent.

PROVISIONAL SPECIFICATION.

Improvements in or relating to Acceleration Control Systems.

We, THE EXPRESS LIFT COMPANY LIMITED, of Greycoat Street, London, S.W.1, a British Company, do hereby declare this invention to be described in the following statement:—

The present invention relates to control systems for controlling the acceleration (or retardation) of a prime mover and is applicable, for example to such systems for controlling a prime mover which is adapted to move a load from a first position to a second position. The invention is concerned more particularly, but not exclusively, with control systems for electrically operated lifts, hoists and the like.

By "prime mover" is means any motive means, such as an electric motor, the acceleration (or retardation) of which may be controlled by a control signal; if the prime mover be a rotating motor then the control signal would be used so as to influence its torque.

The efficiency of a lift depends upon its ability to transfer its load from one floor to another in the least time consistent with mechanical limitations inherent in the lift system and, in the case of a passenger lift, with the comfort of the passengers. The first factor is governed principally by the maximum permissible traction force between the driving sheave and the lift cable, while the second factor is governed principally not by the absolute value of the acceleration or retardation of the lift but by the rate of change of such acceleration or retardation. In an ideal lift system, therefore, the speed of the lift would be varied between zero and a maximum value at a maximum rate, that is to say, the acceleration or retardation would be maintained at a maximum value determined by the mechanical limitations of the system, for the greatest possible part of the acceleration or retardation time, and the acceleration or retardation between zero and this maximum value would be varied at a constant rate.

One object of the present invention is to provide an improved control system for an electrically operated lift, hoist or the like, which takes these considerations into account. A further object of the present invention is to provide in such a control system means for bringing the lift or hoist to rest, or to a suitable stopping speed, at a predetermined position.

It will be appreciated that the invention is applicable not only to the control of lifts, hoists and the like, but also to the position control of loads, for example, in machine tools, which loads are adapted to be positioned by a prime mover, and a still further object of the present invention, therefore, is to provide an improved control system for a prime mover which is adapted to move a load from a first position to a second position.

According to one aspect of the present invention, in a control system for controlling the acceleration (or retardation) of a prime mover, as hereinbefore defined, means are provided for comparing a first control signal, which is a function of the acceleration (or retardation), with a second control signal, which is a function of the speed, and controlling the acceleration (or retardation) in dependence upon the comparison so as to maintain a fixed relation between the two signals and thereby to maintain the acceleration (or retardation) as a predetermined function of the speed.

According to another aspect of the present invention, in a control system for controlling a prime mover which is adapted to move a load from a first position to a second position, means are provided for influencing the torque of the prime mover in accordance with a comparison made between a first control signal which is a function of the acceleration

(or retardation) of the load and a second control signal which is a function of the speed of the load, said means being adapted to influence the torque so as to maintain a fixed relation between the two signals and thereby to maintain the acceleration (or retardation) as a predetermined function of the speed.

The control system may include means for modifying the relationship between the second control signal and the speed of the load in dependence upon a predetermined speed being reached, and may also include control means which are arranged to become operative as the load approaches the second position to control the torque influencing means in dependence upon a comparison made between a control signal which is a function of the speed of the load and a further control signal which is a function of the distance of the load from the second position so as to vary the speed in a predetermined manner.

According to yet another aspect of the present invention, a control system for controlling an electric motor, comprises acceleration- (or retardation-) responsive means for producing a first control signal dependent upon the acceleration (or retardation) of the load, speed responsive means for producing a second control signal dependent upon the speed of the load, means for modifying the said second control signal to produce a pattern acceleration (or retardation) signal which is a predetermined function of the speed, and means for influencing the torque of the motor so as to maintain a fixed relation between the first control signal and the pattern acceleration (or retardation) signal.

According to yet another aspect of the present invention, a control system for controlling the acceleration of a lift, hoist or the like arranged to be driven by a motor, comprises means for influencing the torque of the motor in dependence upon a comparison made between first and second control signals corresponding respectively to the actual acceleration and a pattern acceleration so as to maintain a fixed relation between the two signals, and means for modifying the second control signal in accordance with the speed of the lift, hoist or the like in such a manner that the pattern acceleration varies initially as the square root of the speed from zero to a maximum value, and subsequently, as the speed of the lift, hoist or the like approaches a predetermined maximum speed varies as the square root of the difference between the maximum speed and the actual speed that has been attained so that the pattern acceleration is reduced from the said maximum value to zero.

According to yet another aspect of the present invention, a control system for controlling the retardation of a lift, hoist or the like arranged to be driven by an electric motor, comprises means for influencing the torque of the motor in dependence upon a selected one of two electrical signals, the first signal having a value which is a function of the magnitude of any discrepancy between the actual retardation and a pattern retardation, and the second having a value which is a function of the magnitude of any discrepancy between the actual speed and a pattern speed, switching means normally operative to select the first of said signals but operative, upon the discrepancy between the actual speed and the pattern speed being reduced to zero, to select the second of said signals, means arranged to become operative when the retardation becomes equal to that at which the switching means become operative to select the second signal to maintain the pattern retardation at a constant value until said switching means become operative to select the second signal, and means for controlling the pattern speed in accordance with the position of the lift, hoist or the like whereby the latter is brought to rest, or to a suitable stopping speed, at a predetermined position.

In order that the invention may be clearly understood, one control system in accordance with the present invention, as applied to an electric lift system, will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a schematic circuit diagram of the arrangement;

Figures 2—5 and 7 are explanatory diagrams which will be referred to to explain the operation of the control arrangement; and

Figures 6, 8, and 9 are detailed circuit diagrams showing modifications of the arrangement shown in Figure 1.

Referring to the drawings, and particularly to Figure 1, a control system for an electric lift system having a winding motor 1 with a field winding 2, comprises essentially a Ward-Leonard generator 3 arranged to supply the motor through a resistance 4, and an amplifier 5 feeding the field winding 6 of the generator in accordance with electrical control signals fed to the amplifier, those control signals being controlled automatically in accordance with a required motor torque as described hereinafter.

Coupled with the shaft 7 of the motor are a tachometer generator 8 for providing a signal V proportional to the speed of the motor, an accelerometer 9 for producing a signal proportional to the acceleration of the motor, and two potentiometers 10 and 11 which are adapted to provide signals x and e_v respectively each of which is a function of the actual position of the lift.

The output of the amplifier 5 is controlled in accordance with three input signals, a first signal fed from one end of the resistance 4 which is proportional to the armature

current of the motor, a second signal V from the tachometer generator 8, and a third signal which is dependent upon the position of a relay operated changeover switch 12. In the position shown of the changeover switch 12, the third signal is obtained from a subtracting circuit 13 and its magnitude is equal to the difference between a signal "a" from the accelerometer 9 and a signal obtained from a control circuit comprising a changeover switch 14, a selector circuit 15, a "square-rooting" circuit 16, a voltage reversing circuit 17 and a further selector circuit 18. The selector circuit 15 is adapted to select the smallest of three signals applied to it, these being a signal V from the tachometer generator 8 or a signal V_b, depending upon the position of a changeover switch 19, a signal $V_m - V$ from a further subtracting circuit 20 to which are applied a signal V from the tachometer generator 8 and a constant signal V_m, and a signal V_a or V_b depending upon the position of a changeover switch 21.

The selector circuit 18 is adapted to select the smaller of two signals, one being the output signal from the voltage reversing circuit 17, and the other being obtained from a further control circuit comprising a dividing circuit 22, a squaring circuit 23, a subtracting circuit 24 and a circuit 25 for producing a signal x_a in accordance with a signal a fed thereto from the accelerometer 9. The output from the selector circuit 18 is, of course, only fed to the subtracting circuit 13 when the changeover switch 14 is in its alternative position not shown.

In the alternative position of the changeover switch 12, the third signal fed to the amplifier 5 is obtained from a subtracting circuit 26 which is adapted to produce an output equal in magnitude to the difference between a signal e_v fed thereto from the potentiometer 11 and a signal V from the tachometer generator 8. A further signal from the subtracting circuit 26 is fed to a relay 27 whose operation is described hereinafter.

In describing the operation of the control arrangement, reference will be made to Figures 2, 3, 4 and 5 of the drawings; the operation will be described in two parts, the first part dealing with its operation during acceleration of the motor to a maximum speed, and the second part dealing with its operation during retardation of the motor from the maximum speed to zero.

It will be appreciated that the maximum speed attained by the motor will be selected in accordance with the distance the lift has to travel between two floors, and, as has already been mentioned, the maximum permitted acceleration of the motor is limited by mechanical considerations while consideration of passenger comfort sets a limit on the rate of change of acceleration.

Referring to Figures 2 and 3, which show respectively a speed-time diagram and an acceleration-time diagram of the lift, the arrangement is designed to control the change of acceleration at a uniform rate between zero and a maximum value, the acceleration being increased linearly from zero to a value not exceeding the maximum value, which will be determined by the required maximum speed of the lift. In Figure 3, the rate of change of acceleration is given by the slope of the lines AB and CD, there being shown four graphs a_1, a_2, a_3 and a_4 corresponding to maximum speeds V_{m1}, V_{m2}, V_{m3} and V_{m4}, and the four corresponding speed-time graphs are shown in Figure 2.

The manner of control of the arrangement during acceleration of the motor is based upon the fact that for uniform rate of change of acceleration, or retardation, the speed is linearly dependent upon the square of the acceleration, or retardation; thus it can be shown that

$$a^2 = 2rV^1$$

where a is the acceleration or retardation;
r is the limiting value of rate of change of acceleration or deceleration; and
V^1 is a quantity linearly dependent upon the speed.

It will be seen therefore that if V_m is the maximum speed for a given wind, then the acceleration at any point on the part AB of the graph in Figure 3 can be represented by the equation

$$a = \sqrt{2rV};$$

the acceleration at any point on the part CD of the graph can be represented by the equation

$$a = \sqrt{2r(V_m - V)};$$

and at any point on the part BC of the graph the acceleration has a constant value $\sqrt{2rV_a}$, where V_a is the speed at point B. Thus in order to obtain an acceleration pattern as shown in Figure 3 it is necessary to obtain control signals having values $\sqrt{2rV}$, $\sqrt{2rV_a}$, and $\sqrt{2r(V_m - V)}$ respectively, which are fed to the amplifier 5 in succession.

In operation of the control system, for acceleration of the motor 1, the initial speed and acceleration of the motor are zero and the lift is in its initial position; the changeover switches 12, 14 and 19 are in the position shown in Figure 1. A small initial disturbance of the motor causes a small signal V to be generated by the tachometer generator

8 and this signal V is fed via the changeover switch to the selector circuit 15. Simultaneously with the signal V, a signal $V_m - V$ from the subtracting circuit 20 and a signal V_a via the changeover switch 21, are fed to the selector circuit 15; initially, of course, the signal V is much less than either of the other signals and is therefore selected and passed to the circuit 16. In Figure 1 the output signal from the circuit 15, equal to V, is denoted by V^1. The output signal from the circuit 15, which will be described more fully below, has a value equal to $\sqrt{2rV^1}$ and this is fed via the selector switch 14 to the subtracting circuit 13, the output of which has the value $\sqrt{2rV^1} - a$ where a is the signal from the accelerometer 9. Now the amplifier 5 is adapted to influence the motor torque through the Ward-Leonard drive in such a manner as to reduce this signal $\sqrt{2rV^1 - a}$; it will be seen therefore that the acceleration under these conditions will be equal to the value $\sqrt{2rV^1}$ which acts as a pattern acceleration signal, and the acceleration will increase at a uniform rate.

When the speed of the motor is such that the signal V is larger than the constant signal V_a, the latter will be selected by the selector circuit and consequently the pattern acceleration signal, and therefore the acceleration of the motor will be held at a constant value $\sqrt{2rV_a}$. The point at which the signal V_a becomes selected is represented by the point B in Figure 3, V_a being equal to the speed of the motor when the maximum permissible acceleration is reached. At a point corresponding to the point C in Figure 3, the signal $V_m - V$ from the subtracting circuit 20 becomes smaller than the signal V_a, and is therefore selected in place of the latter. The pattern acceleration signal therefore has a value $\sqrt{2r(V_m - V)}$ and this decreases linearly to zero, that condition being reached when the speed of the motor is a maximum and the lift will move at a maximum speed until further control means become operative to decelerate the motor.

Deceleration of the motor is initiated when the lift reaches a predetermined position at which an inductor is operated to change the changeover switch 14 to its alternative position. This has the effect, because of the presence of the voltage reversing circuit 17, of producing a pattern retardation signal having successive values, $\sqrt{2r(V_m - V)}$, $\sqrt{2rV_a}$ and $\sqrt{2rV}$ and the motor is retarded smoothly, rates of change of the retardation being uniform.

Before the final stages of the retardation are described, however, reference will be made to Figures 4 and 5. Figure 4 shows graphically how the speed of the motor V decreases from a value V_m to zero as the lift approaches the final stopping position, the ordinates of the graph being the square of the velocity and the distance x of the lift from its final stopping position. It will be appreciated that using these co-ordinates the slope of the curve is proportional to the retardation. At the point A, retardation is initiated and the velocity decreases from a value V_m to a value $(V_m - V_a)$ at point B where maximum retardation is reached. The retardation remains constant at its maximum value until point C on the curve is reached and thereafter the retardation decreases to zero at a uniform rate, the speed and retardation of the lift becoming zero as the lift reaches its final stopping position.

However, the curve ABCO in Figure 4 represents an ideal condition in which no errors have arisen in the system; clearly if any errors do arise it may be impossible to bring the retardation and the speed to zero simultaneously when the lift is in the required position. In the figure, the line BC is of constant slope, this being proportional to the maximum value of the acceleration reached.

Referring to Figure 5 now, which illustrates graphically how the speed and deceleration can be made to vary in such a way as to become zero at the required position, the curve ABF shows how the speed would vary if the retardation were controlled in accordance with the pattern retardation signal of value $\sqrt{2_m(Vr - V)}$ and the curve ECO shows how the speed should be made to tend towards zero at the origin O, this curve being represented by the equation

$$V^2 = kx^{4/3}.$$

In order to vary the speed of the lift so that initially its speed and position are represented by point A on the first curve and finally by the point O on the second curve, without varying the retardation in a non-uniform manner, it is necessary to introduce a transition retardation control whereby the movement of the lift is represented by the line BC, this line being tangential to the two curves. The slope of the line BC can be shown to be $V_1^2/_2(x_1 - x_a)$ where V_1 and x_1 are the speed and position at any point on the line BC which is tangential to the curve ECO.

Considering the value of the retardation given by the above expression and the value given by the expression $\sqrt{2r(V_m - V)}$ it will be seen then on the part AB of the curve the former is always greater than the latter; this fact is utilised in controlling the final part of the motion. The method of operation of the arrangement shown in Figure 1 for controlling motion of the lift in the manner described by the curve ABC in Figure 5 will now be described with particular reference to these two figures.

At the position at which retardation is to be initiated, that is to say at point A on the

curve, the changeover switch 14 is caused to move to its alternative position, say by operation of an inductor. A pattern retardation signal having the value $\sqrt{2r(V_m - V)}$ is fed from the selector circuit 18 to the subtracting circuit 13, V_m being the value of the signal V before the lift starts to decelerate. The pattern retardation signal increases at a uniform rate until, at point B on the curve, it is no longer smaller than the signal fed to the selector circuit 18 from the dividing circuit 22 and having the value $V_1^2/_2(x_1 - x_a)$. From point B, the latter signal becomes the new pattern retardation signal and the motion of the lift becomes that described by part BC of the curve. During this part of the motion a signal e_v from the displacement potentiometer 11 is compared with a signal V from the tachometer generator 8 by means of the subtracting circuit 26; the signal e_v is a function of the position of the lift which is such as to correspond to the curve ECO in Figure 5; the line BC has been chosen so as to be tangential to both curves ECO and ABD.

When the lift reaches the position corresponding to point C the signal e_v becomes equal to the signal V and the difference signal $e_v - V$ becomes zero. Consequently the relay 27 is energised, and remains energised, and operates the changeover switch 12. At this point therefore the pattern retardation signal $V_1^2/_2(x_1 - x_a)$ ceases to be effective and the motor is now controlled in accordance with the pattern speed signal e_v, the difference signal $e_v - V$ being fed to the amplifier 5. Thus the motion of the lift continues until the lift reaches the desired stopping position corresponding to the origin of the curve in Figure 6, the lift reaching this position at zero speed and zero acceleration. It will be seen moreover that during the retardation, the retardation is either constant, part BC of the curve, or changes at a constant rate, parts AB and CO of the curve.

In the arrangement so far described, means are provided for producing a pattern deceleration signal of magnitude $V_1^2/_2(x_1 - x_a)$ for controlling the motion of the lift along the part BC of the curve in Figure 5. The arrangement may however be considerably simplified by modifying such means so as to produce a signal of the form $a^1 = (V_1^2 + k_a)/2x_1$ where k_a is a value depending upon the pattern acceleration signal a^1.

Thus, referring to Figure 7, the slope of the line AB is $-(V_1^2 + k_a)/(2x_1)$, the required signal, and this is a particularly convenient quantity to compute since the quantity x_1 can be represented by the displacement of a potentiometer. One circuit for producing such a signal is illustrated in Figure 8.

Referring to Figure 8, a signal V_1^2 is fed through a resistance R_1 to a high gain amplifier 33 across the output of which is a potentiometer P. The tapping of the potentiometer P, connected through the resistance R_2 to the input of the amplifier, is adapted to feed back a signal p, the signal p and the position of the tapping being a function of the distance x_1 of the lift from its stopping position. The signal p has in fact the value $2ax_1$. A further signal k_a is arranged to be fed back to the amplifier through a resistance R_3, this signal being derived from a device 32 for producing the signal k_a in dependence upon the value of an input signal a thereto.

Since the amplifier is of high gain, the voltage e at the input to the amplifier will be very much smaller than any of the signals V^2, k_a, or p. If then the resistances R_1, R_2 and R_3 are of equal value it will be seen that

$$\tfrac{1}{3}(V^2 + p + k_a) = e - O$$
$$\text{or} \qquad V^2 + k_a = -p.$$
$$\text{Now since } p = 2\,ax_1,$$
$$V^2 + k_a = -2ax_1$$
$$\text{or} \qquad a = -(V^2 + k_a)/2x_1$$

which is the required output signal. The device 32 is adapted to produce the required output signal only when the input signal thereto is a. It may comprise non-linear resistances or may be adapted to produce a suitable linear approximation of the form

$$k_a = \text{constant} + (\text{constant} \times a).$$

An alternative method of controlling the motion of the lift to its final stopping position involves the use of a pattern retardation signal during the whole of the retardation period.

If the retardation be given by the expression

$$a = -\tfrac{2}{3}.\,V^2/_2x$$

where a is the retardation;
V is the speed; and
x is the distance of the lift from its final position,

it will be seen that the values of a, V and x all become zero simultaneously and the retardation changes at a uniform rate.

Thus, referring to Figure 5, the motion of the lift may be controlled in the required manner by means of a pattern retardation signal of magnitude $\sqrt{2r(V_m - V)}$ over the part AB of the curve; a pattern retardation signal of magnitude $(V^2 + k_a)/2x$ over the part BC of the curve; and a pattern retardation signal of magnitude $\tfrac{2}{3}V^2/x$ over the part CO of the curve, each of the signals becoming smallest in magnitude, and therefore selected, in turn as the final position is approached.

A circuit arrangement for producing the second and third of these signals is shown in Figure 10, and referring to this figure, the

pattern retardation signal is derived from a dividing circuit 35 to which are fed a signal x in dependence upon the position of the lift and a signal from a selector circuit 36 which is adapted to select the smaller of two signals of magnitude $\frac{2}{3}V^2$ and $\frac{1}{2}(V^2 + k_a)$ respectively. A device 39 is adapted when fed with a signal of magnitude V^2 to produce the signal of magnitude $\frac{2}{3}V^2$, while a further device 37 is adapted, when fed with a signal V^2 and a signal k_a from a circuit 38 the latter being fed with a signal a, to produce the signal of magnitude $\frac{1}{2}(V^2 + k_a)$.

Clearly, in order to apply this circuit arrangement to the general arrangement shown in Figure 1, the parts referenced 11, 12, 26 and 27 would be omitted from the latter and the circuit shown in Figure 9 would replace the parts referenced 22, 23, 24, and 25, the dividing circuit 22 being replaced by the dividing circuit 35.

In order that the speed of the lift may be controlled down to a creep speed, instead of to rest, the arrangement illustrated in Figure 1 may be modified in the manner shown in Figure 6, the latter figure showing a detail of the modified arrangement. Referring to Figure 6, the selector circuit 15 is arranged to select the smallest of three signals of magnitudes V_a, $V_m - V$, and $V - V_c$ respectively, where the symbols V_a, V_m and V have the meanings previously assigned to them and where V_c is a signal whose magnitude is proportional to the desired creep speed. The modification comprises the provision of a further subtracting circuit 30 via which the signal V is fed to the selector circuit 15, and changeover switch 31 which in one position selects the signal V_c to be fed to the subtracting circuit and which in the other position selects a zero signal so that the arrangement operates as if no such modification had been made. It will of course be appreciated that with this modification it will be quite unnecessary to provide a changeover such as 12, Figure 1, for selecting a pattern speed signal towards the end of the wind.

Although the invention has been described with particular reference to a lift system having a driving motor whose torque is controlled by means of electrical control systems, it is to be understood that in its broadest aspect the invention is applicable to the control of any prime mover, as previously defined, by means of control signals which are not necessarily electrical. Thus the control signals may be provided, for example, by any suitable mechanical or hydraulic means.

For the Applicants,
F. S. PEACHEY,
Chartered Patent Agent.

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861,973 3 SHEETS PROVISIONAL SPECIFICATION

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SHEET 1

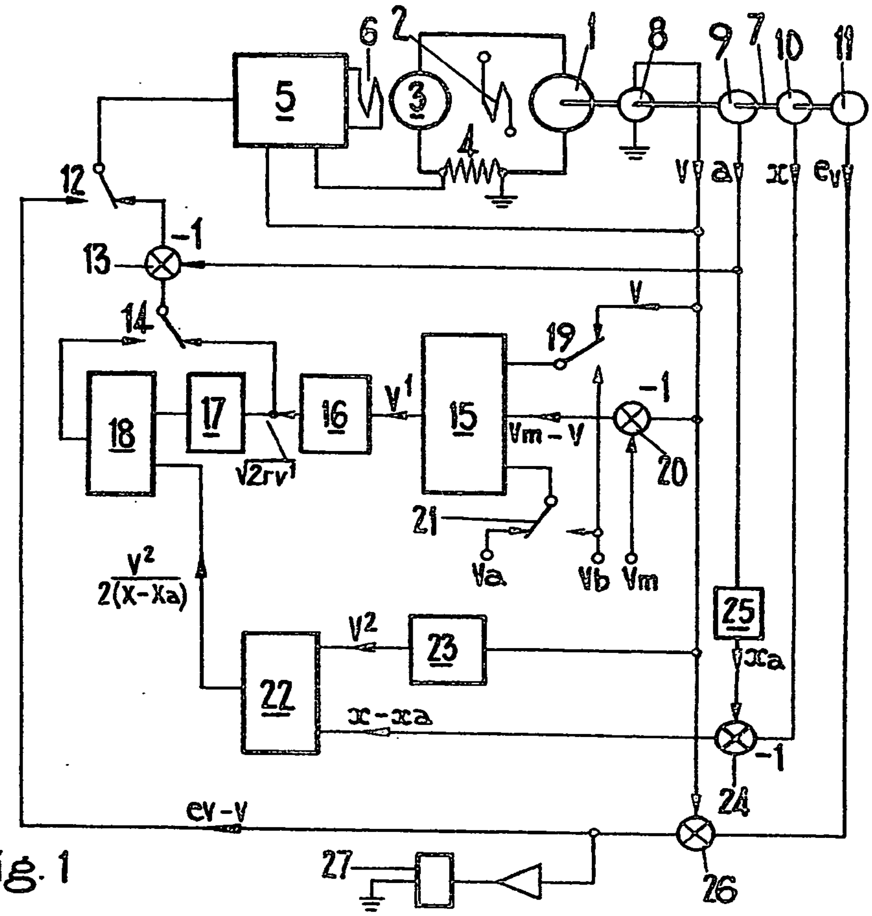

Fig. 1

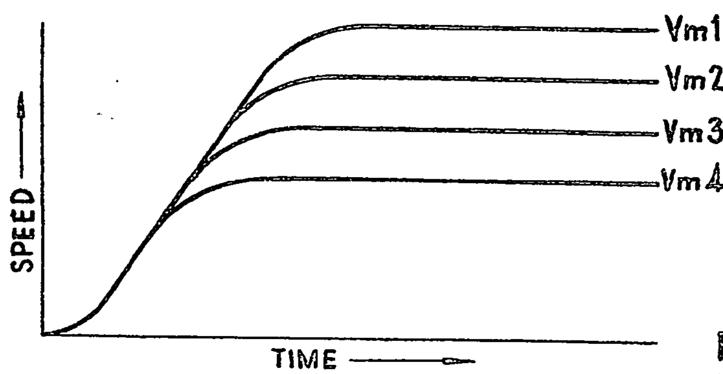

Fig. 2

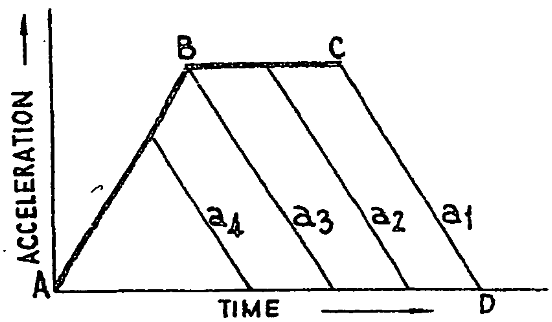

Fig. 3

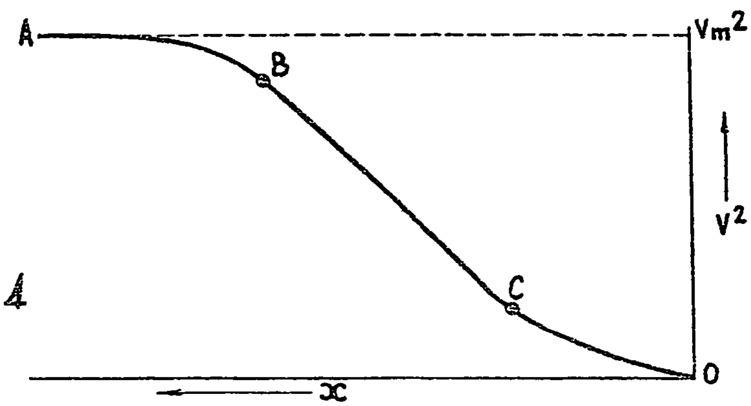

Fig. 4

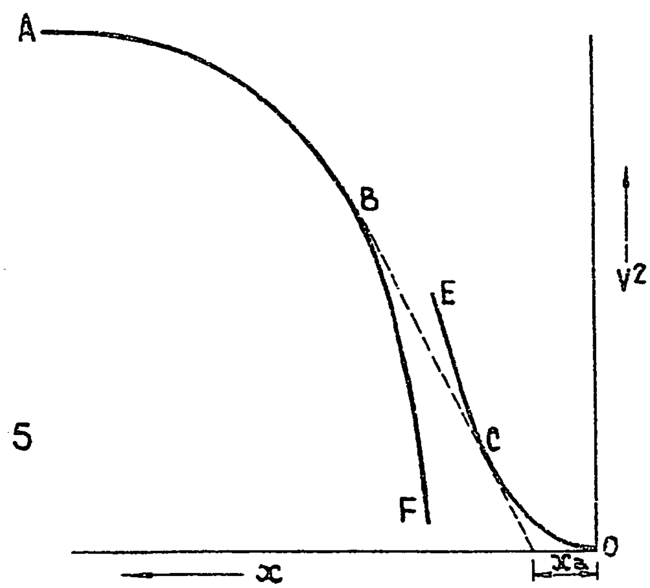

Fig. 5

861,973 PROVISIONAL SPECIFICATION
3 SHEETS
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SHEETS 2 & 3

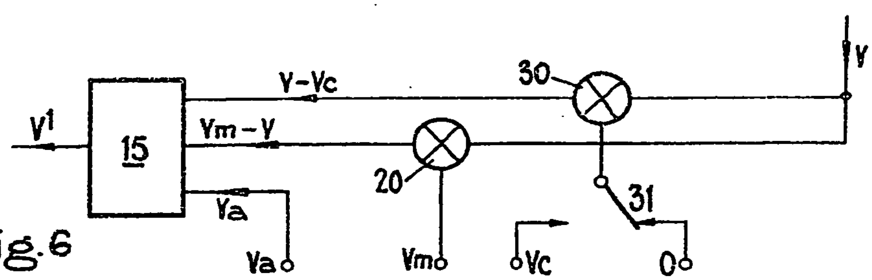

Fig. 6

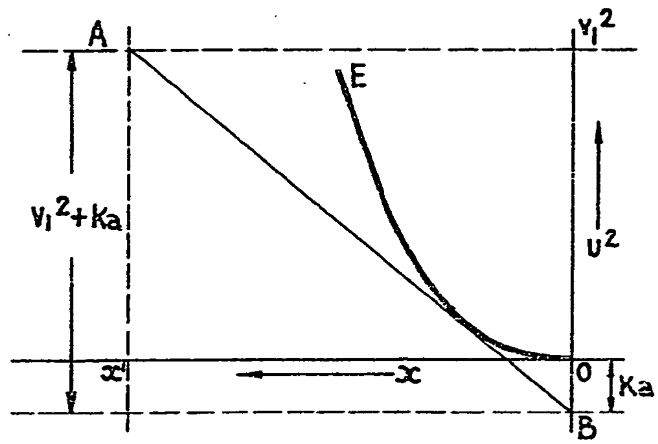

Fig. 7

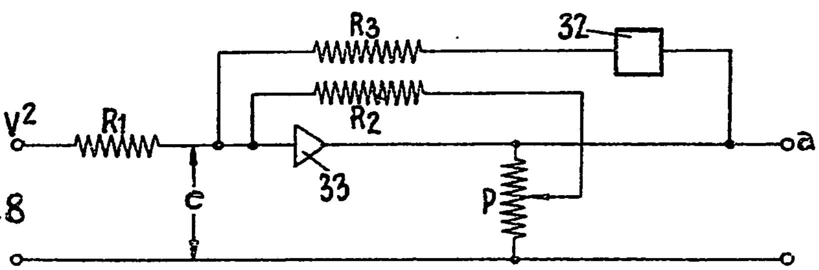

Fig. 8

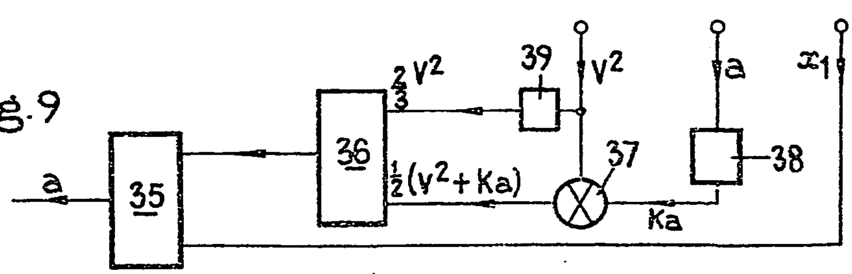

Fig. 9

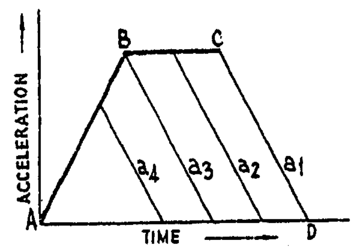

Fig. 3

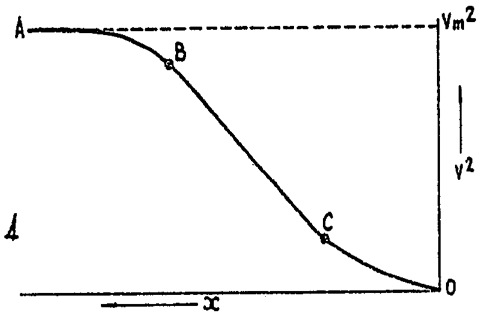

Fig. 4

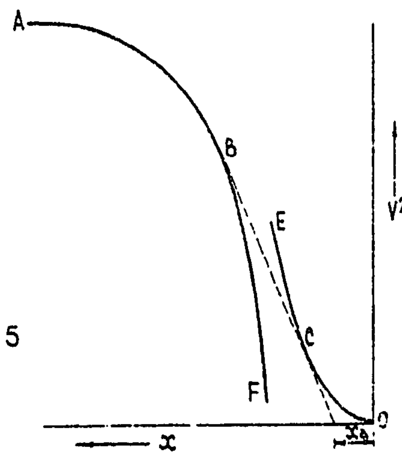

Fig. 5

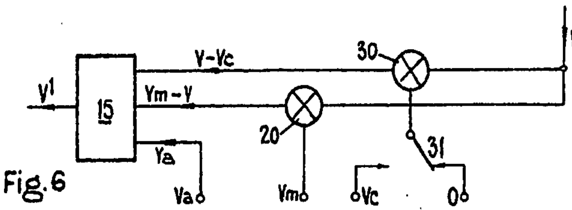

Fig. 6

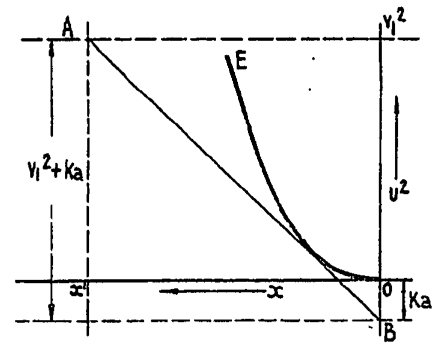

Fig. 7

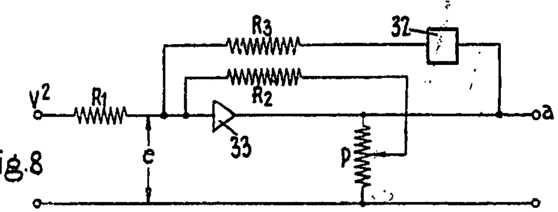

Fig. 8

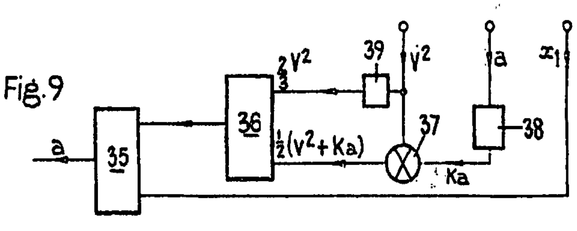

Fig. 9